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INVESTIGATION OF SUPERSONIC THREE-DIMENSIONAL FLOW ABOUT SEGMEN--ETC(U)

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FOREIGN TECHNOLOGY DIVISION

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by

V. B. Minostsev

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О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*ye initially, after vowels, and after ъ, ь; e elsewhere.
When written as ё in Russian, transliterate as yё or ё.

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English	Russian	English	Russian	English
sin	sin	sh	sinh	arc sh	$\sinh^{-1}$
cos	cos	ch	cosh	arc ch	$\cosh^{-1}$
tg	tan	th	tanh	arc th	$\tanh^{-1}$
ctg	cot	cth	coth	arc cth	$\coth^{-1}$
sec	sec	sch	sech	arc sch	sech^{-1}
cosec	csc	csch	csch	arc csch	csch^{-1}

Russian	English
rot	curl
lg	log

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INVESTIGATION OF SUPERSONIC THREE-DIMENSIONAL FLOW ABOUT SEGMENTAL BODIES

V. B. Minostsev

In 1966 in the Institute of Mechanics of the Moscow State University under the leadership of Prof. G. F. Telenin an investigation was conducted of supersonic three-dimensional flow about bodies of segmental shape. For calculation of flow there were used the methods discussed in [1, 2]. In these methods the gas-dynamic functions on the layers are represented by Lagrange polynomials on two variables, and for transition from layer to layer during calculation of the subsonic and transonic regions of flow there is solved a system of ordinary differential equations, during calculation of the supersonic region of flow there is used the method of characteristics. Some of the obtained results of investigations are presented in articles [2-5]. Since the developed methods are adapted for calculation of smooth flows, the contour of the segmental bodies was approximated by a single analytical formula [2-5]. The

utilized approximation made it possible to consider flow around bodies, the contour of which differs from that of the segmental body with break of generatrix virtually only in the region of the maximum cross section. Calculations are performed for numbers $M_{\infty} \geq 5$, angles of attack α to 30°, different central angles of the frontal spherical segment ($2\theta^*$) and different generatrix angles of the rear cone (β). As a result of calculations there are obtained distributions of the gas-dynamic parameters in the shock layer and on the surface of the body, there are constructed shock waves and the patterns of distribution of lines of flow and isobars in the plane of symmetry of flow and on the surface of the body, there is investigated the effect of the real properties of gas on the pattern of flow, distribution of the gas-dynamic parameters and the aerodynamic characteristics. In the report attention is given only to the main qualitative results, obtained on the basis of analysis of calculation data. All the linear dimensions provided in the report pertain to the radius of curvature of the body at the forward point, pressure p to the product of the density of incident flow by the square of maximum velocity.

Figs. 1-6 show the results of calculation of flow around a body, close to sixty-degree spherical sector, on an example of which are examined the properties of flow around bodies of such shape. The pattern of flow around the frontal surface of the body at $M_{\infty}=\infty$ is provided in Fig. 1a, b, c. Solid lines depict the contour of the

body, lines of flow and the shock wave, dashed lines - isobars $\frac{p}{p_{max}}$ (where p_{max} - pressure at the critical point, the position of which for angle of attack $\alpha = 15°$ is marked by an arrow on Fig. 1a), dot-dash - sound line. In Fig. 1 is given the pattern of flow in the plane of symmetry, Fig. 1b and c - on the frontal surface of the body. As calculations show, provided with various angles of attack, the pattern of flow around the frontal surface with increase of angle of attack is changed in the following manner: lines of flow, exiting the critical point, with the exception of the two lying in the plane of symmetry, acquire the preferred direction and at this point have common tangent, which is clearly seen in Fig. 1 c.

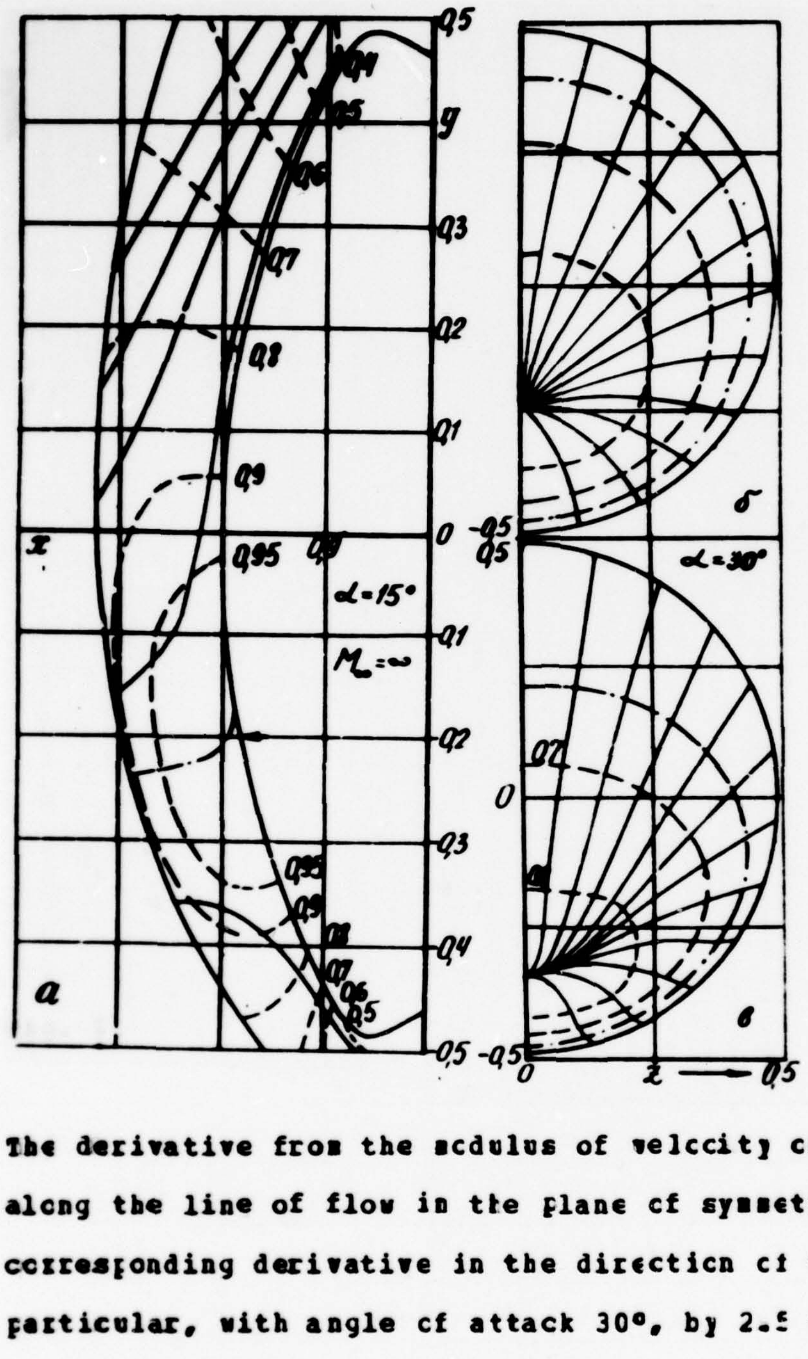

Fig. 1.

The derivative from the modulus of velocity on the length of the arc along the line of flow in the plane of symmetry exceeds the corresponding derivative in the direction of the common tangent, in particular, with angle of attack 30°, by 2.5 times. The displacement of the critical point from the axis of symmetry turns out to be less

than that calculated by Newton theory and, particularly, for angle of attack 30° by approximately 25 o/o. The flow line with maximum entropy lags behind the flow line arriving at the critical point, however, this lag even for angle of attack 30° turns out to be insignificant. The isobars and sound line are deformed, being condensed in the direction parallel to the plane of symmetry.

Fig. 2 shows the field of flow in the plane of symmetry and the projection of the flow line to this plane or the surface of the body.

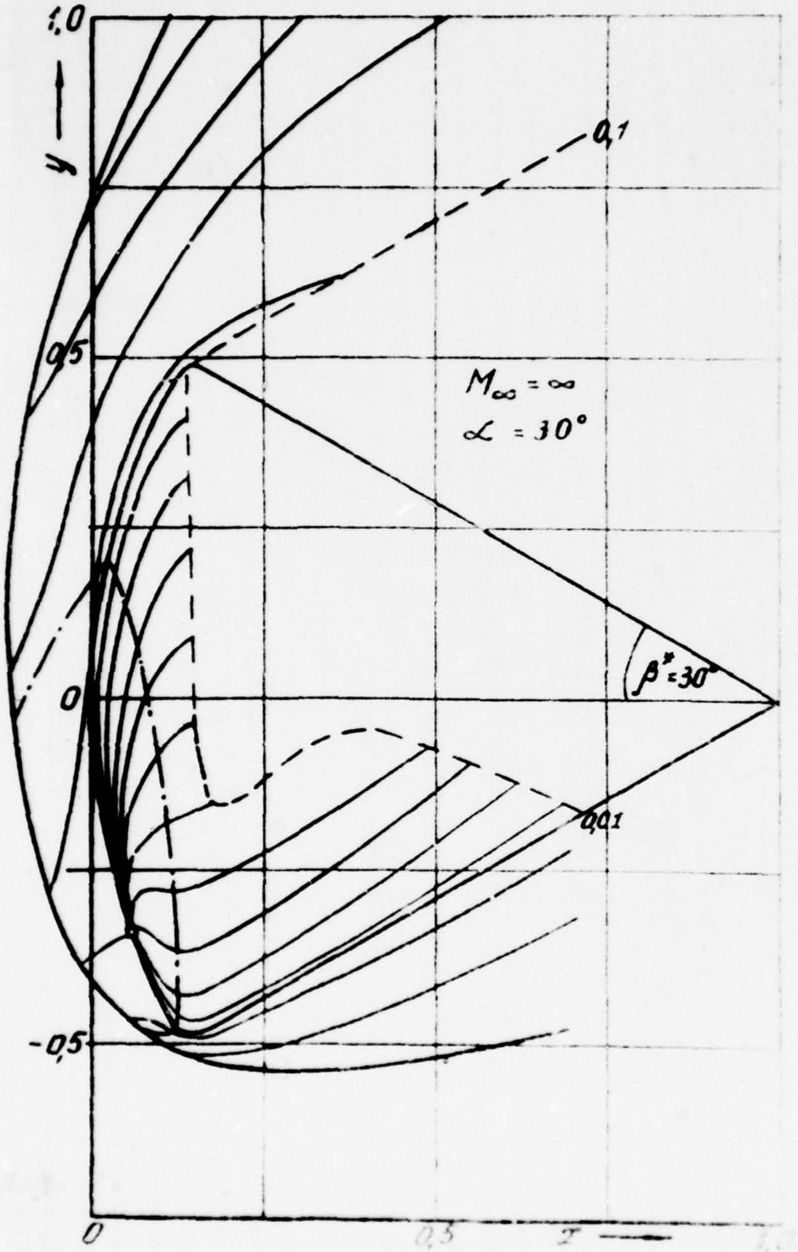

Fig. 2.

The shock wave, flow lines, isobars and sound surface are depicted by the same lines as in Fig. 1. Since the calculations are conducted for

ideal gas, the question should be examined about the effect of viscosity on the obtained pattern of flow, distribution of gas-dynamic parameters and aerodynamic characteristics. Concerning the frontal surface, up to altitudes on the order of 60-70 km the boundary layer is still quite thin and the flow field outside it can be obtained from the calculations of flow by ideal gas. On the lateral surface separation can occur. The magnitude of the separation zone is determined by the angle of attack, geometry of the body and conditions in the incident flow. It is natural that during calculation of ideal gas flow around the body it is impossible to calculate the flow in the separation zone, however, the effect of the separation zone on the flow outside it and the aerodynamic characteristics of the body can be sufficiently well simulated during the calculation of flow around segmental bodies by ideal gas. Actually, during flow around the round area in the area of the maximum cross section there occurs considerable acceleration of flow and sharp pressure drop, which on the leeward side at the surface of the body leads to the formation of a region of very low pressure, in which there is virtually no gas. So the flow density at the surface of the body for the case represented in Fig. 2 on the leeward side of flow is greater than an order lower than the flow density of the windward side of flow. If we take the isobar, corresponding to the experimental value of base pressure, and take it as the boundary of the separation zone, and assume pressure in region $p < p_{дон}$ equal to

$P_{дон}$., during calculation of flow by ideal gas we obtain simulation of the effect of the separation zone on the pattern of flow and the aerodynamic characteristics of the segmental body. The area, simulating the separation zone, is limited in Fig. 2 by broken line.

The physicochemical processes occurring in the shock layer during hypersonic flow around blunt bodies lead to considerable change of the values of gas-dynamic parameters. The conducted investigations [5] showed that the aerodynamic characteristics of ideal gas flow around segmental bodies in the case of near-equilibrium flow around frontal surface with rather high accuracy can be obtained from the calculations of flow around a given body by some simulating ideal gas. In this case the flow around the frontal surface is considered equilibrium, and the adiabatic index for flow, simulating the given equilibrium flow, is selected from the condition of equality of the ratio of densities in direct shock wave for equilibrium and simulating flows. It is shown that the errors obtained with such simulation in the values of gas-dynamic functions in the shock layer in the entire subsonic region do not exceed 2-3 c/o. Calculation of the supersonic region is conducted with the value of adiabatic coefficient, obtained from the condition of "freezing" of the composition of gas in the region of the maximum cross section of the body. Comparisons with results of calculations of axisymmetric nonequilibrium flow [5] indicate the rather high accuracy of such a

system of simulation. Figs. 3-5 show the results of calculation of flow with α = 15° about a body, close to sixty-degree sector. Fig. 3 shows the position of shock waves in the plane of symmetry for the following cases: 1, 2, 3 - $M_\infty = \infty$ respectively monatomic, diatomic and triatomic gases with constant adiabatic indices (γ = 1.66, 1.4, 1.53); 4, 5, 6 - M_∞ = 10, P_∞ = 120 kg/m², T = 230° K, respectively N_2, air and CO_2; 7, 8 - M_∞ = 25, P_∞ = 2.5 kg/m², T = 250° K respectively air (or N_2) and CO_2.

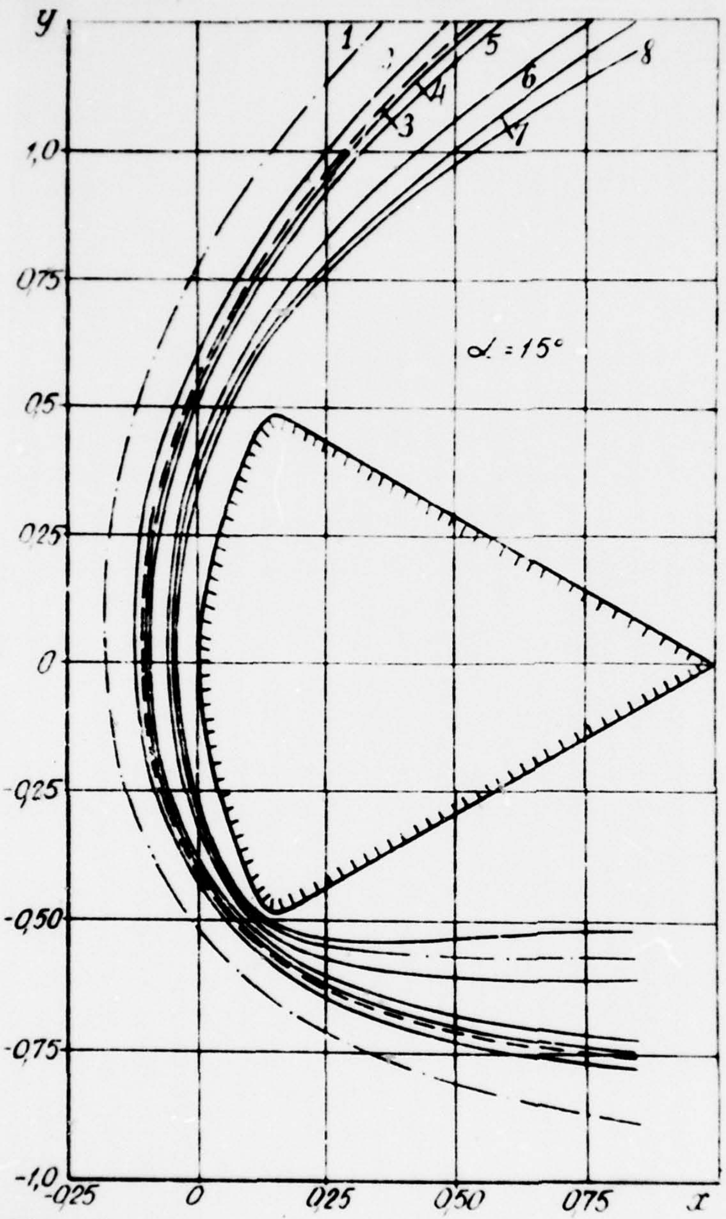

Fig. 3.

For air curves 5 and 7 correspond to conditions at altitude 30 km or 60 km. These same numerical designations of curves are retained in

Figs. 4, 5, where there are provided distributions of pressure along the surface of the body P(x) and across the shock layer P(ξ) in section x $\approx$ 0.36 on the windward side ($\psi = \pi$) of flow $\xi = \frac{r - r_s}{r_w - r_s}$, where r - distance from the axis of symmetry of the body, index s designates the surface of the body, w - shock wave. Increase of γ leads to more intense overexpansion of flow during turn in the region of the maximum cross section than is revealed relative to different dimensions of "spoons" in the distribution of pressure along the surface of the body at curves 1-3 in Fig. 4.

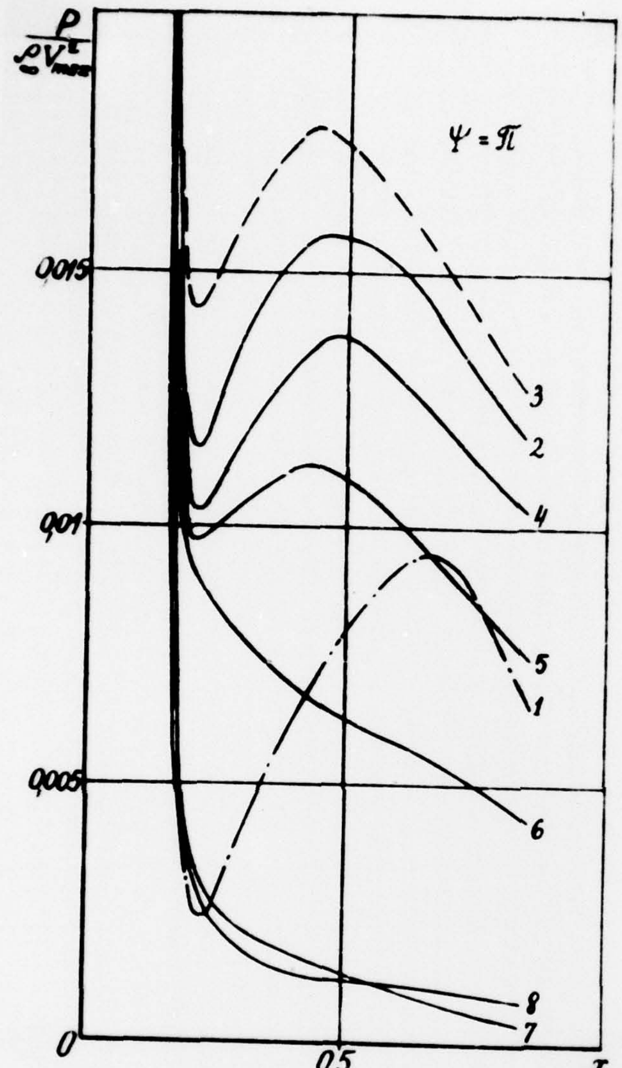

Fig. 4.

The presence of physicochemical processes in the shock layer in the examined case of flow around a body, close in shape to spherical sixty-degree sector, leads to lowering of the pressure on the lateral surface, and consequently, to decrease of the contribution of the

lateral surface of the body in the total aerodynamic characteristics. The differences in the pressure distributions for N_2, air and CO_2 (curves 4-6) are explained by the different values of time of excitation of oscillations and dissociation. If for N_2 under the examined conditions (M_∞ = 10) the effect of real properties cannot practically be considered, the real properties for CO_2 must already be considered. The corresponding values of adiabatic indices of flow, simulating flow around the frontal surface, in the examined cases will be the following: 4 - 1.3 (?1.5?), 5 - [illeg.], 6 - 1.14. With M_∞ = 25 (curves 7, 8) the corresponding values of adiabatic index for flow, simulating flow around the frontal surface, for all three examined cases γ_{e_1} = 1.1, and for "frozen" flow $\gamma_f \approx$ 1.6, which corresponds to almost completely dissociated gas, in view of which the distributions of pressure, obtained by the given method, in all three of the examined cases are virtually identical.

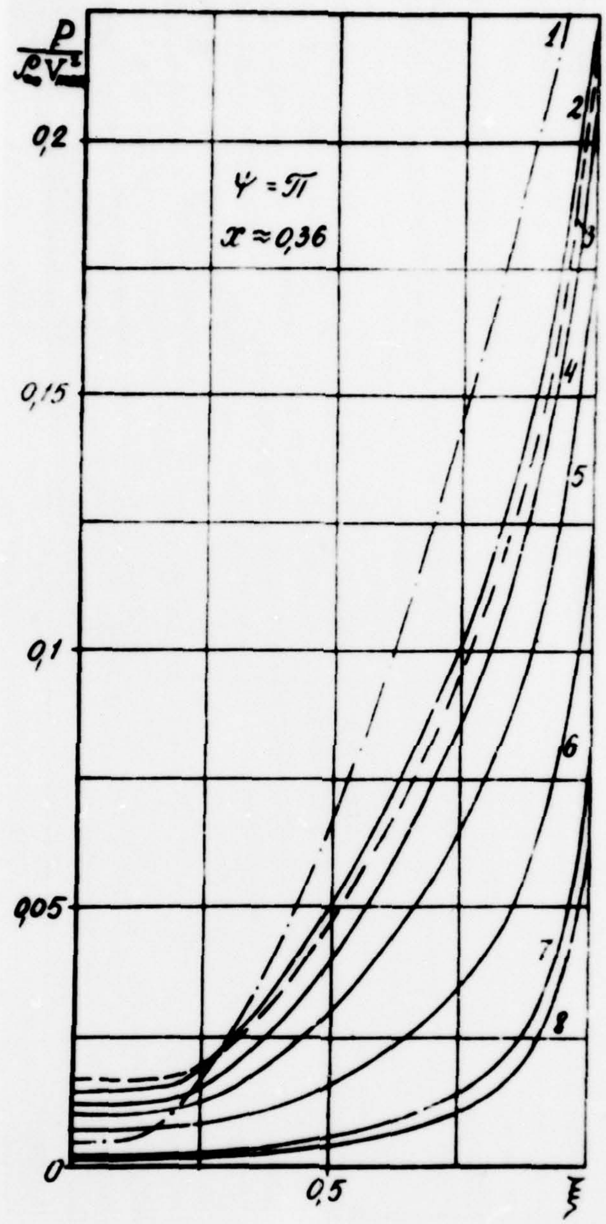

Fig. 5.

Let us examine now some results (Figs. 6-11) of investigation of flow around elongated segmental bodies by perfect gas (γ = 1.4). Analysis of calculation data show that for elongated segmental bodies

even with small angles of attack and small angles of back cone there is considerable run-over of flow, which leads to the fact that pressure on the leeward side of the body starts from a certain length to exceed the pressure on the windward side. The indicated length in the considered range of angles of attack virtually do not depend on the angle of attack (Fig. 6).

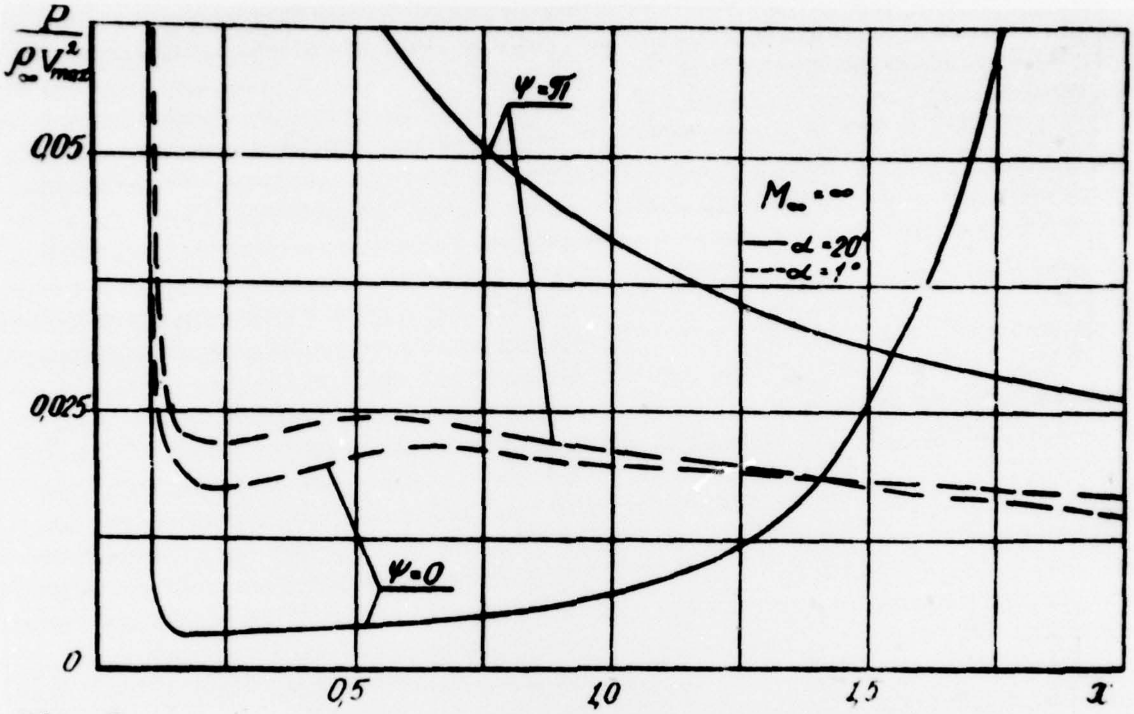

Fig. 6.

Large pressure gradients, appearing at considerable angles of attack, for example $\alpha = 20°$ (solid lines in Fig. 6) lead to separation and reorganization of flow. However, the fact described above occurs even for angle of attack 1° (broken line on Fig. 6). Fig. 7 shows the pattern of flow lines on the surface of the body in the projection to the plane of symmetry at angle of attack $\alpha = 20°$.

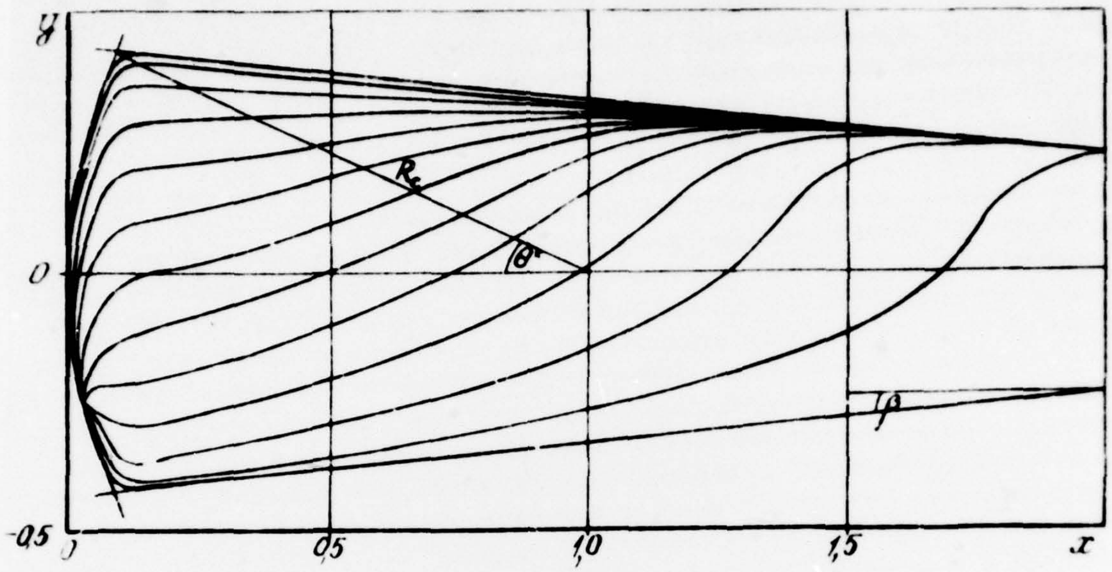

Fig. 7.

The data presented in Figs. 6, 7 are calculated with $M_\infty = \infty$, $\theta^* = 25°$, β 5 . The experimental data of Yu. Ya. Karpeyskiy, shown by points in Fig. 8, for the case of flow around a body with break of generatrix at $M_\infty = 6$, $\alpha = 10°$, $\theta^* = 30°$ and $\beta = 10°$ indicate the quite good coincidence of calculated and experimental data.

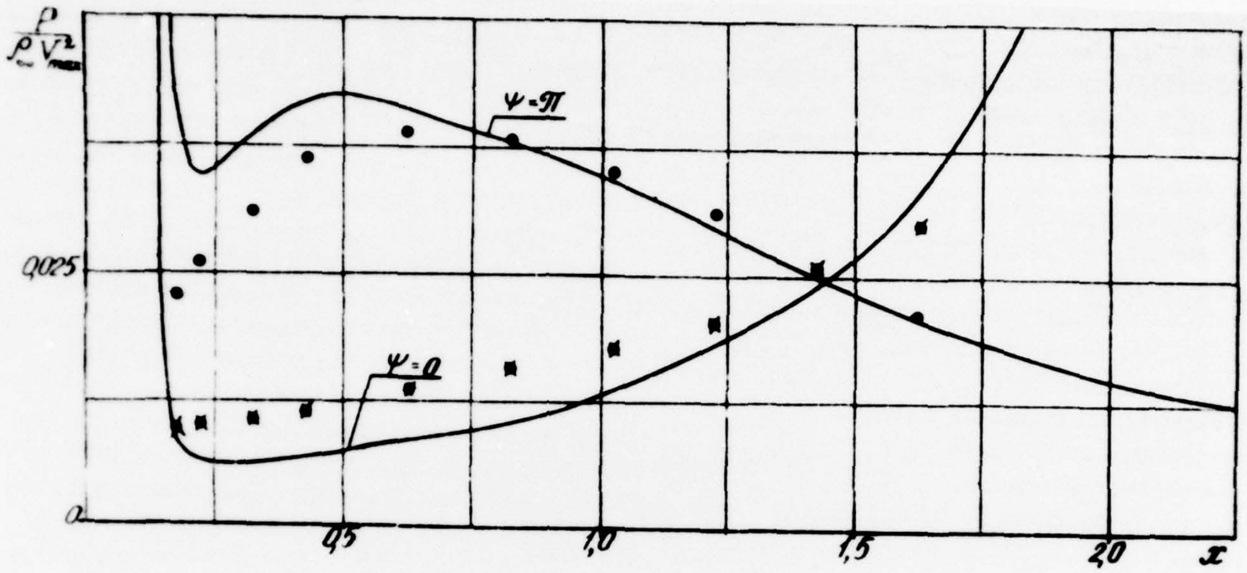

Fig. 8.

The most difference is in the region of the maximum cross section of the body, which, in all probability, can be explained by the effect of rounding of the approximating contour. In Fig. 9 for the given case of flow there are shown the pressure distributions with respect to meridian angle [redacted].

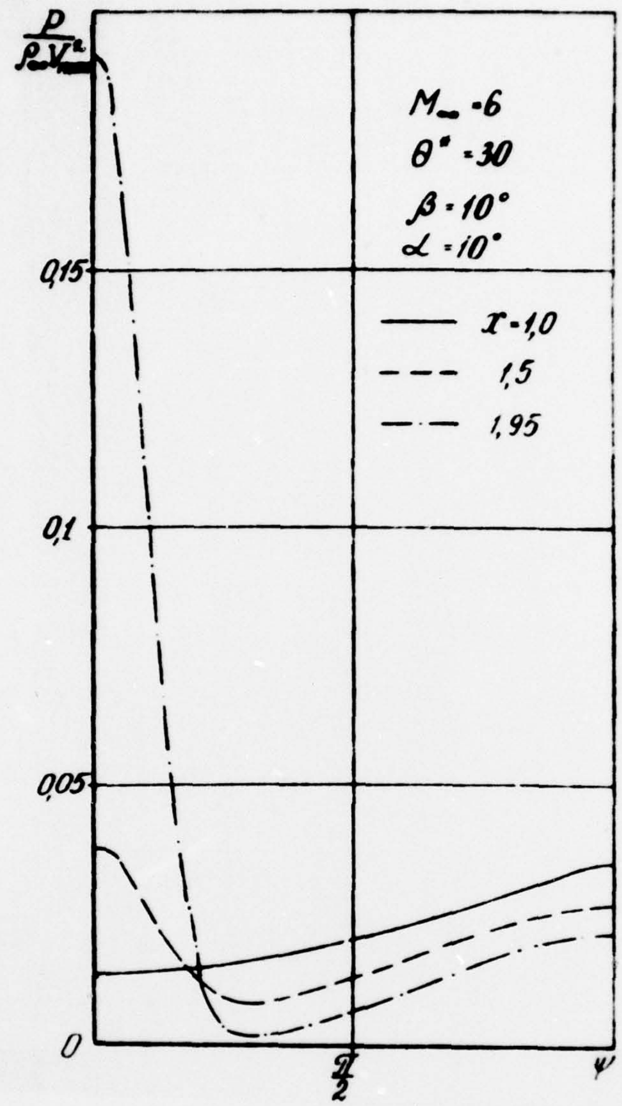

Fig. 9.

Bith large x from the leeward side the pressure sharply rises, which leads to the appearance cf positive radial velocities at the surface cf the body from the leeward side (Fig. 10), i.e. to curving of the flow lines near the surface of the body (Fig. 11).

The broken line on Fig. 11 depicts the characteristics of the first family in plane $\psi=0$.

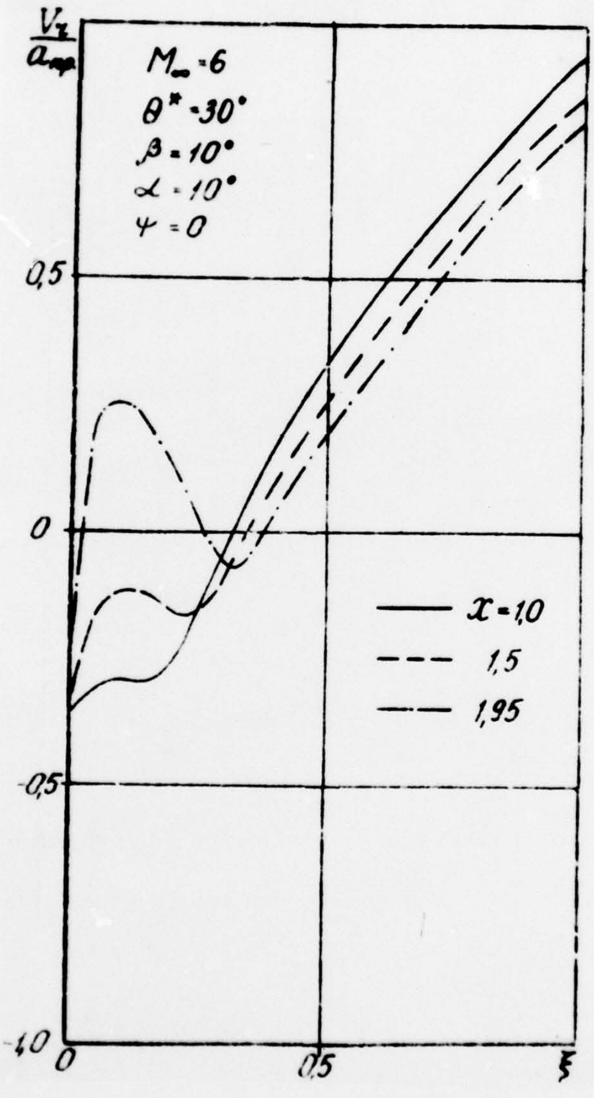

Fig. 10.

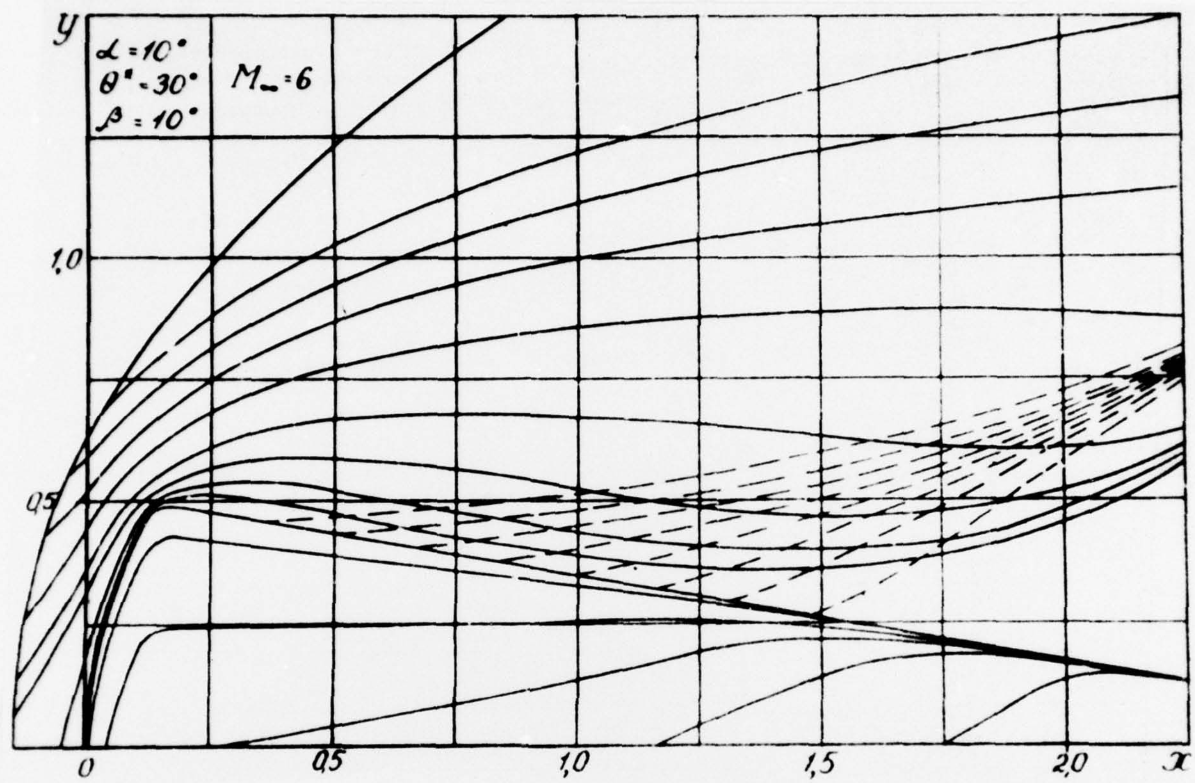

Fig. 11.

It is seen that the characteristics, proceeding from the surface of the body in range 0.5 < x < 1.5, virtually flow together at x = 2.5, i.e., run-over of flow near the surface of the segmental body leads to the formation of suspended shock wave in the field of flow from the leeward side of flow.

REFERENCES

1. G. P. Telenin, G. P. Tinyakov. Method of calculation of three-dimensional flow around bodies with departed shock wave. DAN USSR, 1964, Vol. 154, No. 5, p. 1056-1058.

2. V. B. Minostsev. Method of calculation of supersonic three-dimensional flow around smooth bodies. IAN USSR, MZhG, 1967, No. 2, p. 126-133.

3. V. B. Minostsev, G. P. Telenin, G. P. Tinyakov. Investigation of the pattern of supersonic three-dimensional flow around segmental-shaped body. DAN USSR, 1968, Vol. 179, No. 2, p. 304-307.

4. Yu. N. D'yakonov, V. B. Minostsev, G. P. Telenin. Supersonic three-dimensional flow around blunt bodies. In the collection "Problems of hydrodynamics and continium mechanics". Science, 1969, p. 213-220.

5. M. G. Lebedev, V. B. Minostsev, G. P. Telenin, G. P. Tinyakov. Approximate method of calculation of the reality of gas during hypersonic flow around segmental bodies. IAN USSR, MZhG, 1969, No. 2, p. 107-111.

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